An examination of economic efficiency of Russian crop production in the reform period

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Abstract

This article examines economic efficiency (EE) of crop production of Russian corporate farms for 1993–1998. EE declined over the period, due to declines in both technical and allocative efficiency. Technical efficiency (TE) results indicate that output levels could have been maintained while reducing overall input use by an average of 29–31% in 1998, depending on the method used, while the allocative efficiency (AE) results show that costs could have been reduced about 30%. The EE scores show that Russian corporate farms could have increased efficiency by reducing the use of all inputs, particularly fertilizer and fuel. Russian agriculture inherited machinery-intensive technology from the Soviet era, which may be inappropriate given the relative abundance of labor in the post-reform environment. Investment constraints have prevented the replacement of old machinery-intensive technology with smaller scale machines that allow for a more labor-using technology.

JEL classification: P2, Q1

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1. Introduction

When reform of the agricultural sector in Russia began in 1992, many analysts predicted that farm managers would change their objectives from meeting output quotas to becoming profit maximizers. Consequently, this change was expected to improve the productivity and efficiency of their operations. After an initial dip in agricultural production, therefore, Russian agriculture was supposed to recover significantly. This recovery in agricultural production has only recently shown signs of materializing, after almost a decade of reform.

Russian agriculture's slow response to reform is reflected in measures of the relative efficiency of crop production in state and collective farms (corporate farms). Two recent studies of technical efficiency (TE) in Russian agriculture showed that the average farm's TE performance, the ability to minimize physical input use for a given output level, has declined compared to the best domestic practice (Sedik et al., 1999; Sotnikov, 1998).[1] The

decline in TE was explained by such factors as self-sufficiency efforts, competing private plot output, and the share of state subsidies in revenues.

The goal of this study is to measure the economic efficiency (EE) of corporate farms in Russia for 1993–1998. Measurements of EE reflect the ability of producers to achieve both TE and allocative efficiency (AE) (cost minimization). Other similar studies on transition countries' agriculture have focused on other related issues. To mention a few, these have included agricultural total factor productivity growth at the aggregate level in Russia (Voigt and Uvarovsky, 2001) and the former Soviet republics (Lerman et al., 2001); farm-level TE in Russia (Brock, 1996) and Ukraine (Jensen et al., 1996; Kurkalova and Carriquiry, 2002); regional TE in Ukraine (Murova et al., 2000); and comparisons across transition economies (Macours and Swinnen, 2000). With EE, the failure to minimize costs can be attributed to mistakes made at the farm level, and region- or economy-wide distortions. The emphasis in this article is on the analysis of distortions at the regional level, rather than farm-level mistakes, for reasons outlined below.

Measuring EE will allow at least two important questions to be addressed. One question is, how much could farm performance be improved if all farms in Russia were to adopt the best domestic practice? A related question is, which input markets suffer from the greatest distortions? Given the answer to the

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[1] The definition cited is for an input orientation. An alternative definition is for an output orientation—the ability to achieve more output for given input levels. Output and input orientation scores are identical under constant returns to scale (Färe et al., 1994). This study uses an input orientation throughout the analysis.

second question, it should be possible to focus on the input markets where reform is most needed in order to help Russian farms emulate the best domestic practice. The evidence presented in this article suggests that there is much room for improving EE, using a domestic best practice standard, and that the magnitude of the input market distortions are in some cases quite severe.

Because EE measurement involves the construction of a cost function, it is useful to discuss some issues in cost function estimation and how these issues are addressed in the present study. First, any estimate of a cost function requires that the prices used in the estimation be measured accurately. This does not appear to be a problem in Russia. The price data in this study come from a yearly survey by Goskomstat, the Russian statistical agency, which asks a sample of 10% of all corporate farms what their prices and expenditures are on their inputs.

Another issue related to cost function estimation is that market prices may not capture all incentive signals, i.e., they do not accurately reflect producers' opportunity costs. In this case, the cost-minimizing bundle implied by market prices may not correspond to the producer's true cost-minimizing bundle. If farmers are in fact minimizing costs, then an estimate of AE measures the extent to which market prices diverge from a farmer's opportunity costs. When such a divergence is caused by farm policy or some other source common to a group of producers (such as a poorly functioning credit market), cost-minimizing producers will consistently over- or underutilize inputs, and this bias will be reflected in the AE measurement.

Essentially there are two cost-minimizing bundles, one represented by market prices and one corresponding to farmers' incentives (including market prices plus distortions). Removing the distortions in farmers' incentives would cause the farmers to choose the bundle consistent with overall opportunity costs. Consequently, AE estimates can be used to measure biases caused by market distortions. This latter issue is particularly relevant in Russian agriculture, because it is known *a priori* that there are nonmarket incentives to overuse certain inputs in Russian agriculture that are not fully represented in their market price.

There are several examples of the incentives that Russian farm managers face to use inputs in ways that are inconsistent with the factors' input demand functions. One example is the tendency to maintain full employment at the farm level, irrespective of the real wage rate. This occurs because farm managers often lack short-term credit, so local governments frequently provide soft credit or inputs from their reserves in exchange for a share of the resulting crop. As part of the exchange, government officials often put pressure on farm managers to maintain full employment. Thus, there is an incentive not contained in the market price of labor to employ more than the optimal number of workers.

Another example of nonprice incentives is the overuse of labor-saving machinery inherited from the Soviet era. The results in this article suggest that farm managers might be able to improve their AE and EE by switching to smaller scale, relatively more labor-using machinery. However, given the current state of farm-level reform in Russia—in particular the poorly functioning credit market—it is unlikely that farm managers are able to invest in machinery appropriate for the new market-oriented input mix. If that is the case, it may be rational for them to use the old Soviet machinery. In this case, the lack of a credit market is a hidden cost to investing in more appropriate machinery, which is not represented in the machinery price data.

This study uses regional data to construct representative farm observations for each region in Russia. The representative farms are assumed to be cost-minimizing producers, perhaps facing price distortions. The AE scores will be interpreted as a measure of the degree of input market distortions faced by cost-minimizing producers, rather than the ability of producers to minimize costs. In this sense, the approach taken here closely mirrors that used in an environmental economics study in which AE results using shadow prices were interpreted more as a reflection of market distortions rather than cost-minimizing ability (see Bhattacharyya et al., 1994). In Appendix A, we argue that with farm-level observations, it should be possible to decompose the allocative inefficiency measure into a "price distortion" component common to all farms (which also accounts for regional differences in TE) and an "inefficiency" component unique to each farm. Because the "inefficiency" component would be unbiased by definition, it would cancel out for a representative farm calculated from regional data (subject to some caveats—see Appendix A). This necessarily follows from the assumption that prices faced by farms within a region are identical. As discussed later, the fact that prices show little variation at the regional level is one reason why measures of AE are rare. The wide geographic dispersion of farms in different regions in Russia allows us to avoid this problem.

Finally, an interesting side point emerges from this analysis. To estimate AE, shadow prices for land have to be derived, as rental rates are unavailable in the study period due to the slow pace of Russian land reform. The implicit prices derived in this study may be useful to the ongoing debate about land reform in Russia.

This article is organized as follows. Section 2 presents the methodologies that are used to estimate EE and AE. The data used in the estimation are discussed in Section 3. The results are presented and discussed in Section 4. Section 5 concludes the article by highlighting how much corporate farm performance could be improved and reviewing input market distortions. Appendix A provides an argument showing that farm-level inefficiency effects offset at the regional level, so that allocative inefficiency scores reflect distortions in the economy. Appendix B includes a discussion of the shadow land prices derived in the analysis. Appendix C assesses the robustness of the stochastic frontier production function estimates by comparing it with alternative models and specifications. Appendix D provides detailed TE and AE scores.
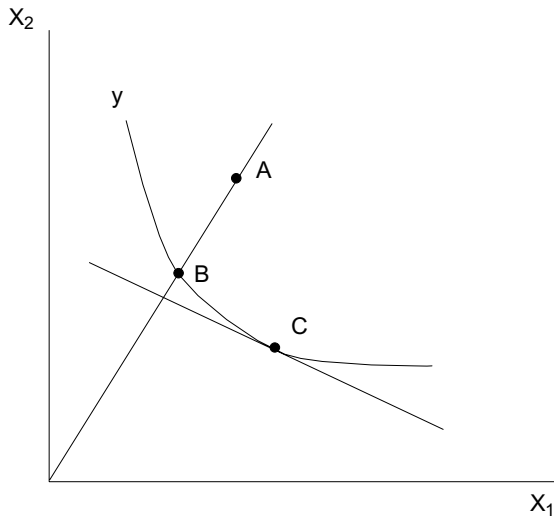
Fig. 1. Relationship between technical, allocative, and economic efficiency.

2. Methodology

Recent studies of efficiency have their roots in the seminal article by Farrell (1957). Farrell made a distinction among TE, AE, and EE. TE with an input orientation refers to the ability to minimize physical input use for a given output level. AE refers to the ability to achieve cost minimization for a given output level. EE refers to the combined effect of achieving both TE and AE.

These ideas are illustrated in Fig. 1. Point A is technically inefficient since it is located on the interior of the production isoquant for output level y^o; that is, the same output could have been achieved with fewer inputs (x_1 and x_2), given the best practice frontier. Point B is technically efficient since it is on the isoquant for output y^o; however, this point is not allocatively efficient since it is not on the isocost line like point C. Since point C is both technically and allocatively efficient, it is economically efficient.

An input-oriented approach to measuring EE will yield three sets of inputs: (1) the observed set, $\mathbf{x}^o$; (2) the technically efficient set, $\mathbf{x}^{te}$; and (3) the economically efficient set, $\mathbf{x}^{ee}$. The cross products of these input sets with the input price vector $\mathbf{w}$ yields the costs of the observed, technically efficient, and economically efficient input set, respectively. These costs can then be used to devise measures of TE, AE, and EE:

$$TE = \mathbf{w}'\mathbf{x}^{te}/\mathbf{w}'\mathbf{x}^o, \tag{1}$$

$$EE = \mathbf{w}'\mathbf{x}^{ee}/\mathbf{w}'\mathbf{x}^o, \tag{2}$$

$$AE = \mathbf{w}'x^{ee}/\mathbf{w}'\mathbf{x}^{te} (=EE/TE). \tag{3}$$

There have been two main approaches used to measure efficiency, discussed in more detail below: the parametric approach known as stochastic frontier analysis (SFA) and a nonparametric approach, data envelopment analysis (DEA). Both approaches are implemented and the results compared.

Most empirical studies of efficiency have focused on TE. There have not been as many studies of AE, for reasons discussed below—in fact, the vast majority of efficiency studies have focused on TE (for recent surveys, see Berger and Humphrey, 1997; Sieford, 1996). A few of the studies that have examined both TE and AE include: Schmidt and Lovell (1979); Kopp and Diewert (1982); Ferrier and Lovell (1990); Evenson and Bravo-Ureta (1994); Xu and Jeffrey (1998); and Sharma, Leung and Zaleski (1999). This study most closely follows the study by Evenson and Bravo-Ureta, but the comparisons are limited given the institutional issues raised in this article.

The most formidable obstacle to studying EE appears to be practical: examining overall EE requires a comprehensive database on output, input, and prices. This issue is not a problem in this study since a comprehensive database is available on output, inputs, and prices for Russian agriculture in the reform period. Another problem, usually associated with micro-level data, is the lack of price variation that results when producers face common regional prices, which makes econometric estimation difficult. This is not a problem either since this study uses observed market prices for several inputs over many regions, which are spatially separated over the largest country in the world (in terms of land mass). There is plenty of price variation, given the lack of infrastructure as well as local policies that at times have restricted agricultural trade flows between regions. Another reason why there are relatively few AE studies is that they encounter technical econometric estimation problems; these issues are discussed below.

2.1. Parametric approach

A standard methodology using parametric techniques is followed to estimate TE, AE, and EE. The primary parametric approach is the SFA (Aigner et al., 1977; Meeusen and van den Broeck, 1977). Here, a farm's production function is specified and econometrically estimated

$$y_i = f(\mathbf{x}_i; \beta) + \varepsilon_i. \tag{4}$$

If the error term, ε_i, is found to be nonspherical, it is decomposed into a pure noise component, v_i, and an inefficiency component, u_i, that is, $\varepsilon_i = v_i - u_i$. The expression of TE relies on the value of the unobservable u_i, which must be predicted. These predictions are obtained by deriving the expectation of the appropriate function of u_i conditional on the observed value of $v_i - u_i$ (Battese and Coelli, 1988, 1992; Jondrow et al., 1982). Assumptions must be made about the shape of the efficiency score distribution. The most commonly used distributions have been the half-normal and truncated normal, which generally have been found to be reasonable approximations of efficiency distributions.[2] For panel data models, there have been a few

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[2] The half-normal distribution was proposed in Aigner et al. (1977). The truncated normal distribution was proposed in Stevenson (1980). The gamma distribution was also proposed by Greene (1980).

different proposals about how to model inefficiency patterns over time. This study uses the exponential time model.[3]

Some economists have proposed estimating AE econometrically with a system of equations, where factor demand equations are estimated simultaneously with the cost equation. There are two main objections to this approach: (1) the solutions require numerical search methods, which sometimes are unstable in nonlinear estimation and (2) the issue of how to treat the error terms (including AE effects) in the cost function and the error terms in the factor demand equations has not been adequately addressed.[4] Coelli et al. (1998) recommend the single equation approach, assuming the modeling assumptions are appropriate and there are suitable data available. This is the approach taken in this study.

Given the estimate of the production function and the inefficiency component u_i, the observed output of farm i, y_i, can be filtered for noise by subtracting the inefficiency component from the technically efficient output, $f(\mathbf{x}_i; \beta)$:

$$y_i^o = y_i - v_i = f(\mathbf{x}_i; \hat{\beta}) - u_i. \tag{5}$$

As shown below, the Cobb–Douglas production function was tested and found to be an appropriate representation of the technology, so the optimal input use ratios of a cost-minimizing farm were considered to be independent of output. This property was used to calculate the technically efficient input set. The dual properties of the Cobb–Douglas function are used to form the cost frontier and to derive the economically efficient input set.

The software used to estimate the SFA models was the FRONTIER (4.1) software program, which uses the technique of replacing the error variances σ_v^2 and σ_u^2 with $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2/(\sigma_v^2 + \sigma_u^2)$ (note $\gamma \in [0, 1]$).[5] The closer γ is to one, the more error variance is attributable to inefficiency; if γ is zero and statistically insignificant, then an OLS model would be appropriate. The program estimates TE under the half-normal distributional assumption with maximum likelihood techniques. The assumption of a zero mean can be tested with an estimated parameter μ; if this parameter is statistically significant and nonzero, then the half-normal distribution may be centered away from zero. The program assumes that TE grows or decays exponentially; that is $u = u_i \exp(-\eta(t - T))$, where η is a parameter to be estimated. The normal error term is assumed to be independently, identically distributed (i.i.d.) as $v \sim N(0, \sigma^2)$; the inefficiency terms u_i are also assumed to be i.i.d. as $N(\mu, \sigma^2)$ but are truncated from the left at zero.

2.2. Nonparametric approach

The nonparametric approach is known as DEA (Charnes et al., 1978). Estimating TE with the constant returns to scale assumption and an input orientation (denoted as $F^I(\cdot \mid C)$) is calculated by solving the following mathematical program:

$$\begin{aligned} TE &= F^I(x, y \mid C) &(6)\\ &= \underset{\theta, \mathbf{z}}{\text{Min}} \, \theta \quad \text{s.t.} \quad y_i \leq \mathbf{zY}\\ &\qquad\qquad\qquad \mathbf{zX} \leq \theta x_i\\ &\qquad\qquad\qquad z_i \geq 0, \quad i = 1, \ldots, J, \end{aligned}$$

where θ is the efficiency score, J is the number of regions, $\mathbf{X}$ denotes the $J \times X$ matrix of the X observed inputs, $\mathbf{Y}$ denotes the $J \times Y$ matrix of the Y observed outputs, and $\mathbf{z}$ is a J-dimensional vector that denotes the intensity variables or weights that are used to construct piecewise linear production frontiers. The scale assumption can be changed to variable returns to scale (VRS) by modifying the program so that the intensity variables sum to one, i.e., $\sum z_i = 1$. Since constant returns to scale in the production function were found to hold with econometric tests, the DEA scores were estimated for the constant returns to scale programming problem.

EE, denoted by Q^I, is calculated by solving a similar linear programming problem

$$\begin{aligned} EE &= Q^I(\mathbf{w}, y \mid C) &(7)\\ &= \underset{\mathbf{z}, \mathbf{x}}{\text{Min}} \, \mathbf{wx} \quad \text{s.t.} \quad \mathbf{zY} \geq y_i\\ &\qquad\qquad\qquad x_i \geq \mathbf{zX}\\ &\qquad\qquad\qquad z_i \geq 0, \quad i = 1, \ldots, J. \end{aligned}$$

where Y, X, and z are the same variables as above. The programming solutions, $\mathbf{wx^{ee}}$, provide piecewise approximations of the linear cost frontier, which are used to calculate EE scores ($\mathbf{wx^{ee}}/\mathbf{wx^o}$). Given the solutions of Eqs. (6) and (7), AE is calculated by using the relationship in Eq. (3). These solutions were calculated using the DEAP software program.[6]

There have been a few studies comparing the parametric and nonparametric approaches (e.g., Ferrier and Lovell, 1990; Hjalmarsson et al., 1996; Neff et al., 1993; Wadud and White, 2000). The advantages and disadvantages of each approach are well known. SFA allows one to obtain parameter values and statistical significance levels, and separate random noise from efficiency levels. However, SFA is criticized sometimes for requiring an arbitrary specification of the functional form and efficiency distribution. DEA relaxes the specification assumptions, but is often criticized for confusing random noise with efficiency levels.

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[3] For different proposals about how to model inefficiency patterns over time, see Cornwell et al. (1990), Kumbhakar (1990), and Battese and Coelli (1995). This study uses the exponential time model proposed by Battese and Coelli.

[4] However, a solution to this problem has been proposed for the translog cost function (Kumbhakar, 1997).

[5] The FRONTIER 4.1 computer software program was developed by T. Coelli, University of New England, Centre for Efficiency and Productivity Analysis, 1996. The variance technique was proposed in Battese and Corra (1977).

[6] The DEAP 4.1 computer software program was developed by T. Coelli, University of New England, Centre for Efficiency and Productivity Analysis, 1996.

3. Data

The analysis focuses on crop production and input use for corporate farms at the oblast level (equivalent to provinces or states). Corporate farms are the dominant type of farm in Russia, accounting for approximately 91% of arable cropland and supplying about 90% of grain and sugarbeet production and slightly less than half the livestock output.[7] The oblast-level data are divided by the number of corporate farms in each oblast in order to model a representative farm. Ideally, farm-level data should be used to measure efficiency, although in this instance farm-level data are not available. Many macro-level efficiency studies assume the existence of a representative consumer, firm, or farm, which is consistent with the approach used here (see Appendix A for more on the interpretation of AE scores of a representative *farm*).

The data used to estimate efficiency come from statistical publications of Goskomstat and the Russian Ministry of Agriculture, 1999. The data were available for 70 oblasts annually for 1993–1998. It should be noted that the early years of the sample are characterized by high inflation. Month-on-month inflation was brought under 5% for the first time in July of 1995, and was relatively stable until the August 1998 financial crisis (International Monetary Fund, 2000). Discussion of the AE results will focus on the later years of relative price stability.

The value of output and the input quantities were measured as follows. Output was measured as the value of crop output in real 1983 rubles.[8] For the input quantities, land was measured in thousands of hectares of cropland sown under crops, adjusted for quality (Goskomstat, 2001). The quality adjustment was proxied as the pre-reform ratio of the oblast's average grain yield to the national average grain yield. This measurement was compared with the "bal" agroclimatic measurements, which are available only for a smaller group of oblasts, and shown to be highly correlated. Labor was measured as mandays used in crop production (Goskomstat no longer separates out labor expenditures on crops and livestock, so the proportion of expenditures on labor was estimated using the ratios calculated by Sedik et al., 1999). Fertilizer and fuels were measured in thousands of tons, estimated by dividing total expenditures on fertilizer and fuels by their average prices (Goskomstat, 1999). Machinery was calculated as the product of total available horsepower and average annual depreciation rates to represent tractors "consumed" in production (Goskomstat, 1999).[9]

Input prices were measured in the following ways. For labor, average daily wages were calculated by dividing monthly salaries by the number of mandays worked in the month (Goskomstat, 2001). For fertilizer, fuel, and tractors, surveyed average prices were available from price index publications (Goskomstat, 1999, 2000). Goskomstat estimated these prices by asking a sample of 10% of all agricultural enterprises in Russia what their prices and expenditures were on their inputs during the year in question. The expenditure numbers for fuel purchases were revised upwards in 1995, and the 1993 and 1994 numbers have been adjusted using the ratio of pre- and post-revision numbers for 1995 (since the revised numbers for 1993 and 1994 are not available). Land prices were derived in the parametric analysis discussed below.

4. Results

4.1. Efficiency results

The first issue that had to be addressed in this study was land prices. This is an important methodological issue as there were no land markets in Russia in the period studied, and consequently no land prices.[10] A few different approaches were considered. The approach that was taken was to use the SFA method with a Cobb–Douglas production function (which was tested and found to be a suitable representation of the technology) to derive the long-run shadow prices using duality theory, making the assumption that land is a quasi-fixed input. The assumption necessary to derive these shadow prices is that land use is consistent with its long-run opportunity cost (that is, land is used efficiently). In our view, using the shadow prices derived in this way with its strong assumption is better than assuming an arbitrarily low price for land. In a Cobb–Douglas context, assuming an arbitrarily low price is equivalent to assuming the efficient amount of land use should be arbitrarily large. These land shadow prices then were used in the nonparametric approach.

The SFA Cobb–Douglas production function was tested to determine whether it was a suitable production function. This was done by estimating the more flexible translog production function and then restricting it to the Cobb–Douglas function. The restriction did not result in a significant loss of fit, so the Cobb–Douglas function (shown below) was accepted. Restricting the cross-product of input coefficients to zero resulted in a χ^2 statistic of 16.52, with 15 degrees of freedom. Rejection of the restriction requires a statistic greater than 22.31 at the 10% level. The frontier Cobb–Douglas production function that was estimated was the following (see Table 1 for details):

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[7] Private subsidiary garden plots, which are attached to corporate farms, account for 5% of arable land. These are distinct from private farms, which account for 4% of arable land. The private subsidiary plots account for more than 50% of the value of total crop output, but produce mostly vegetables and potatoes. The Russian statistical agency Goskomstat recently has begun paying more attention to private household farming. The implications of the obvious productivity advantage of private versus corporate farming in Russia will be discussed in the conclusions.

[8] Unfortunately, this is the latest available constant price output measurement available for the study.

[9] The data for total horsepower are missing for 1997, so the values are interpolated from the 1996 and 1998 numbers in each region. Depreciation rates were

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unavailable for 1993 and 1994, so the average depreciation rate for 1995–1998 was applied to the earlier years' data.

[10] There have been several attempts to pass land reform legislation in Russia since the reform era began. A complete land code finally passed in 2002, but during the time period studied land transactions were not legal and the use of land as collateral was strictly forbidden.

Table 1
Estimates of Cobb–Douglas production function frontier and comparisons with other production functions

Country aggregation sub-sector technique	This study		Other studies		
	Frontier		Sedik	Lerman	Kurkalova
	Russia per oblast crop frontier	Cost share (percent)	Russia regional crop frontier	USSR[†] per worker Ag. OLS	Ukraine farm level grain Baysian[‡]
Inputs					
Constant	−3.177**		−4.875**	−0.796**	5.32
	(0.270)		(0.351)	n.a.	(0.670)
Land	0.331**	(29)	0.219**	0.257**	0.160
	(0.040)		(0.046)	n.a.	(0.130)
Labor	0.614**	(53)	0.469**	n.a.	0.058
	(0.077)		(0.057)	n.a.	(0.028)
Fertilizer	0.017	(1)	0.075**	0.143*	0.135
	(0.013)		(0.017)		(0.032)
Fuel	0.072*	(6)	0.036*	—	0.309
	(0.037)		(0.017)		(0.093)
Machinery/capital	0.123*	(11)	0.091*	0.043	—
	(0.068)		(0.048)		
Frontier parameters					
σ^2	0.338*		0.232	—	—
	(0.201)		(0.185)		
γ	0.878**		0.839**	—	—
	(0.073)		(0.130)		
μ	0.024		−0.131	—	—
	(0.514)		(0.649)		
η	−0.106**		−0.405**	—	—
	(0.019)		(0.070)		
Log likelihood function	−4.440		n.a.	—	—
LR test	210.580		n.a.	—	—

n.a. = not applicable or available.

— = not estimated.

** significant at the 0.01.

* significant at the 0.05.

[†] Northern republics.

[‡] Baysian results provide standard deviations in the parentheses.

$$\ln y_i^{\text{te}} = -3.18 + 0.33 \ln x_i^1 + 0.61 j \ln j x_i^2 + 0.02 \ln x_i^3$$
$$+ 0.07 \ln x_i^4 + 0.12 \ln x_i^5, \tag{8}$$

where the x_i^j are land, labor, fertilizer, energy and machinery for $j = 1, \ldots, 5$, respectively, and $y_i^{\text{te}} = f(\mathbf{x}_i; \hat{\beta})$ is the technically efficient production given the x_i^j. It should be noted that these results show that the return to scale is 1.16, but an F test indicated that the returns to scale were not statistically significantly greater than 1. The restriction that the returns to scale were equal to 1 returned an F test of 2.60, while the critical value for an F test with one restriction and 75 degrees of freedom is 3.97. For comparison, other estimates of agricultural production functions in Russia and Ukraine are provided in Table 1.

In estimating production functions econometrically, endogeneity can be an important problem. There also may be questions in this particular context whether the SFA model is really measuring inefficiency or whether it is capturing differences in land quality and climatic conditions. Alternative models and specifications, including fixed and random effects models under various assumptions about regional climate and land quality

differences, show that the production coefficients are generally stable across models. However, there were some minor differences with some variables (particularly fuel and machinery), which suggest that the results may be a little fragile for those variables, warranting some caution in their interpretation.

The corresponding dual cost function to the SFA production function is derived analytically from the cost-minimization problem associated with the production function (Eq. (8)) (see e.g., Varian, 1992, chapter 4). This derived cost function for (8) (with land, $\bar{x}_i^1$, as a quasi-fixed factor) was used to form the cost frontier:

$$\ln C(\mathbf{w}_i, y_i) = 3.97 + \ln w_i^1 x_i^1 + 0.73 \ln w_i^2 + 0.02 \ln w_i^3$$
$$+ 0.08 \ln w_i^4 + 0.14 \ln w_i^5$$
$$+ 1.2 \ln y_i - 0.4 \ln \bar{x}_i^1. \tag{9}$$

The cost function frontier represents overall EE, which comprises TE and AE components. Using the relationship in (3), AE scores were "backed out" for each region by dividing the minimum cost of producing y_i^{o}, $\mathbf{w}'\mathbf{x}^{\text{ee}}$, by the technically efficient cost, $\mathbf{w}'\mathbf{x}^{\text{te}}$. The minimum cost frontier for each region

Table 2
Summary of SFA and DEA-C scores, Russia national average

	SFA	DEA-C*
Technical efficiency		
1993	0.81	0.77
1994	0.79	0.83
1995	0.77	0.65
1996	0.75	0.66
1997	0.73	0.61
1998	0.71	0.68
Allocative efficiency		
1993	0.86	0.78
1994	0.83	0.77
1995	0.74	0.71
1996	0.70	0.73
1997	0.70	0.75
1998	0.70	0.70
Economic efficiency		
1993	0.70	0.60
1994	0.66	0.64
1995	0.57	0.46
1996	0.53	0.48
1997	0.51	0.45
1998	0.50	0.48

*DEA-C = data envelopment analysis with constant returns to scale.

Table 3
Decomposition of economic (in)efficiency by source, technical efficiency (TE) versus allocative efficiency (AE)

	SFA		DEA	
	TE	AE	TE	AE
1993	0.37	0.63	0.46	0.54
1994	0.40	0.60	0.54	0.46
1995	0.49	0.51	0.38	0.62
1996	0.49	0.51	0.38	0.62
1997	0.47	0.53	0.33	0.67
1998	0.45	0.55	0.44	0.56

was obtained by inserting observed values of $\bar{x}_i^1$, w_i^2, w_i^3, w_i^4, w_i^5, and y_i into (9), as well as the calculated shadow land prices w_i^1 (whose derivation is discussed in Appendix B, which also discusses the resulting prices).

Table 2 shows the average EE, TE, and AE scores of the SFA and DEA approaches. Because the econometric tests of the production function approximate constant returns to scale, the DEA scores that were estimated and reported were also for the constant returns to scale programming problem (Eq. (6)). It is interesting to compare the TE scores to those in earlier studies that showed that TE declined from 1991 to 1995 (Sedik et al., 1999; Sotnikov, 1998). The new data shows that this trend may be slowing. According to the TE estimates, inputs could have been reduced by 29–32% in 1998 (SFA and DEA scores, respectively). An alternative interpretation, given the constant returns to scale, is that output could have been increased by about 29% using the same amount of inputs. Both the AE and overall EE results have declined since 1993, but have been generally stable since 1995.

The inefficiencies have real ruble costs that can be decomposed into their technical and allocative components. In terms of Fig. 1, the costs of technical inefficiency can be considered the cost of not being on the production frontier (distance AB), while the costs of allocative inefficiency can be considered the cost of not producing in accordance with minimum cost ratios (distance BC). SFA analysis shows that TE losses accounted for about 37–49% of all economic losses while DEA shows TE losses between 33% and 54% (Table 3). By contrast, SFA puts AE losses between 51% and 63% while DEA puts AE losses between 46% and 67%. The results are much more stable and consistent over 1995–1998, the period of relative price stability.

SFA puts TE losses between 45% and 49% while DEA puts the losses between 33% and 44%. AE losses account for 51–55% of total economic losses with SFA and 56–67% of losses with DEA.

Some of the patterns of representative farms in particular oblasts offer interesting results (detailed results are available in Tables A.1 and A.2). The farms in oblasts that displayed high TE scores tend to show high AE scores as well (the correlation was $\rho = 0.84$). Thus, Novosibirsk, not known for its enthusiasm for reform, showed relatively high TE and AE scores (recall that the data being analyzed are for corporate farms, not private farms or subsidiary plots). Nizhnyj Novgorod, in contrast, is considered highly reform-oriented, but never exceeded a ranking of 28th in AE or TE scores. The low-efficiency scores in Nizhnyj Novgorod may simply reflect a neglect of corporate farming in favor of more efficient private farming.

4.2. Interpreting the allocative efficiency distortions

As discussed earlier, it is possible to use the efficient cost shares to diagnose problem areas in input markets. Table 4 shows that the farms in oblasts that performed the best were those that had the highest cost shares in land and labor, and the lowest cost shares for fertilizer, fuels, and tractors. This cost share summary disguises the key fact that EE could be increased by reducing use of *all* inputs—but some more than others.

4.2.1. Labor
This study shows that farms in the most efficient oblasts are the ones that spend the largest share of their costs on labor. These oblasts show labor cost shares that are statistically significant and lower than the optimum, but they are higher than the labor cost shares in the least efficient oblasts. However, previous studies of the labor market in Russian agriculture have pointed out the excess labor extant in that industry (Kapeliushnikov and Aukutsionek, 1995). Thus, it might appear that there is an important disagreement in the research on this issue. These seemingly contradictory findings can be reconciled, first by carefully interpreting the results in this study, and then by understanding some of the rigidities in the labor markets.

Table 4
Comparison of cost shares between most and least allocatively efficient regions, SFA method*

	Land	Labor	Fert.	Fuel	Tractors
Optimal cost shares	0.29	0.53	0.01	0.06	0.11
1993					
10 most efficient regions	0.27*	0.46*	0.03*	0.14*	0.09
10 least efficient regions	0.22*	0.34*	0.03*	0.33*	0.08
1994					
10 most efficient regions	0.26*	0.44*	0.05*	0.16*	0.09
10 least efficient regions	0.21*	0.30*	0.04*	0.37*	0.09
1995					
10 most efficient regions	0.25*	0.39*	0.04*	0.23*	0.09
10 least efficient regions	0.17*	0.22*	0.03*	0.49*	0.09
1996					
10 most efficient regions	0.24*	0.34*	0.03	0.23*	0.16*
10 least efficient regions	0.16*	0.18*	0.11*	0.41*	0.14
1997					
10 most efficient regions	0.25*	0.37*	0.04	0.19*	0.15
10 least efficient regions	0.16*	0.18*	0.09*	0.42*	0.16
1998					
10 most efficient regions	0.25*	0.38*	0.06*	0.19*	0.12
10 least efficient regions	0.15*	0.17*	0.13*	0.39*	0.15

* Statistically significant difference at the 5% level.

While it may be true that there is redundant labor on agricultural enterprises, the same can be said for almost all of the inputs used in Russian agriculture. A farm that is technically inefficient is one that could reduce all inputs and maintain the current output. The allocative inefficiency scores, which suggest that the cost efficient regions are those with high cost shares of labor, do not address the overall *level* of input use, but rather the optimal *mix* of inputs. Thus, when the AE scores indicate that the cost-minimizing mix of inputs has a relatively high share of labor, it is effectively indicating that the use of other inputs (in this case, energy and fertilizers) could be decreased more than the use of labor. The high cost share of labor indicated by the AE score does not necessarily imply that productivity will improve by hiring more workers.

At the same time, there are rigidities in the labor market that contribute to what appears to be excess labor in the sector. One symptom of labor rigidity is that laborers persist in showing up at their jobs even when they have not been paid for as much as six months. Some of the rigidity of the Russian labor market can be explained by the peculiarities of the housing market, where a large proportion of apartments remained unprivatized. In regions where privatization of housing has not occurred, the supply of privatized housing is restricted, increasing the costs of finding a new dwelling. One recent study of labor mobility found that regions with low rates of apartment privatization have lower overall labor mobility (migration in and out of the region) (Brown, 1997).

Another source of labor market rigidity can be explained by the management practices of Russian enterprises. One study showed that the use of in-kind payments that cannot be monetized, such as medical services and vacation facilities, allows firms to retain workers, despite attractive alternatives elsewhere

(Friebel and Guriev, 1999). Regions that use relatively more in-kind compensation have been shown to have relatively lower incomes and lower labor mobility.

4.2.2. Land

As mentioned earlier, during the period studied there was no land market in Russia. In 2002, the Russian Duma passed amendments to the Land Code (passed in 2001) that allow for the regulation of the agricultural land market. The amendments took effect in January 2003 and allow for the sale of land and its use as collateral, although foreigners and companies whose foreign capital exceeds 50% may not buy land. It should be possible in the near future to collect land prices from the resulting transactions. It will be interesting to compare these prices to the shadow price estimates calculated in this study.

4.2.3. Fuel

The main source of allocative inefficiency appeared to be the large cost share of fuel consumption. According to the dual cost function derived from the production function, the efficient cost share of fuel consumption for Russian agriculture on average was 6%. The most efficient farms had cost shares that ranged from 14% to 23% over 1993–1998, while the least efficient farms had cost shares ranging from 33% to 49%.

There may be three different possible explanations for the relatively high fuel cost inefficiency. One possible source of excessive fuel consumption may be the tendency to pay workers in kind, either explicitly through direct in-kind payments, or implicitly by allowing workers to steal agricultural inputs for their own use. A 1997 survey of Russian households, the Russian Longitudinal Monitoring Survey, revealed that 8% of employees in the survey received in-kind payments (Friebel and Guriev, 1999). However, the survey did not indicate the share of in-kind payments in total remuneration among enterprises that use it. Furthermore, no survey of Russian agricultural enterprises has investigated the extent of input theft by employees. Perhaps further research would shed some light on this issue.

A second possible explanation is that what may seem to be "excessive" fuel consumption may be a result of stockpiling fuel for barter. Fuel may have been used as a barter tool to finance other input purchases or to pay laborers in kind. For example, the price list on one tractor factory's website at one point stated that prices were negotiable and barter transactions would be considered, with food products and fuel the most desirable barter products.[11] To the extent that fuel and fertilizer were stockpiled to remunerate labor, labor would be more expensive than the ruble wages would suggest, and therefore may not actually be underused (the corollary being that the amount of fuel and fertilizer use may actually be efficient).

The third possibility is that the high cost share of fuel in Russian agriculture may result from fuel inefficiency of Russian

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[11] The Cheliabinsk tractor factory, http://chtz.chelyabinsk.ru/prais.html. In 2000, the website was changed to state that only cash or checks would be accepted.

tractors. However, recent tests have shown that a new Belarus tractor (in wide use in Russia) has about the same, if not better in some instances, fuel consumption performance as a new western tractor. These results are based on a comparison of five Belarus tractors with western tractors of similar horsepower. Data are from OECD tractor tests carried out in the 1990s by the Nebraska Tractor Test Laboratory (Lincoln, NE; test results obtained by correspondence in 2000). In 1999, specialists of the North-Caucus Machine Testing Station compared the "Don-2600" of the Rostov tractor factory "RostSel'Mash" with Case's "Case-2366" under Russian harvesting conditions. They found that the "Don" produced 18.8 tons of grain per hour, using 2.26 l of diesel per ton, with losses of 2.02%. The "Case" tractor produced 16.3 tons of grain an hour, using 2.34 l of fuel per ton, with losses of 2.34%.

Russian tractors may nevertheless be less fuel-efficient because they are poorly maintained. In 1998, one tractor-testing laboratory tested the reliability of 92 tractors produced by nine different foreign and domestic factories. The study was conducted by the Center for Scientific and Technical Cooperation for the Testing of Agricultural Machinery, located in Solnechnogorsk in the Moscow oblast. This study focused on the number of breakdowns the machines experienced, rather than yield and fuel consumption. The study reported the price paid for the tractors, the frequency of breakdowns, and the primary reasons for the breakdowns. The best performing Russian tractor broke down an average 7.5 times over a period of two years. The worst performing Western tractor, the "Mega-208" from the German company "Klaas" broke down an average 1.8 times over the same period. The laboratory concluded that Russian tractors break down much more often than their Western counterparts, while spare parts availability for the Western tractor manufacturers was much better. The workers of the laboratory have over the years noticed the same flaws in the construction of Russian combines: bad welding, low reliability of the cooling system, belts, and especially ball bearings. Not one producer has organized a repair service for its combines. At the same time, the German company "Klaas" has already established a repair service in Novosibirsk. The American firm "Case" has created a technical center in Omsk.[12]

Not only is the spare parts market for agricultural machinery in Russia underdeveloped, but agriculture officials complain that the scarcity of agricultural machinery forces Russian farmers to cover much more land in their tractors and combines than their western counterparts, leading to excessive wear and tear. This may also lead to poorly maintained tractors that are fuel inefficient.

4.2.4. Tractors

In addition to the tractor issues discussed above that influence fuel use, the EE results suggest that Russian agriculture may not have adapted well to the changes in input prices since the
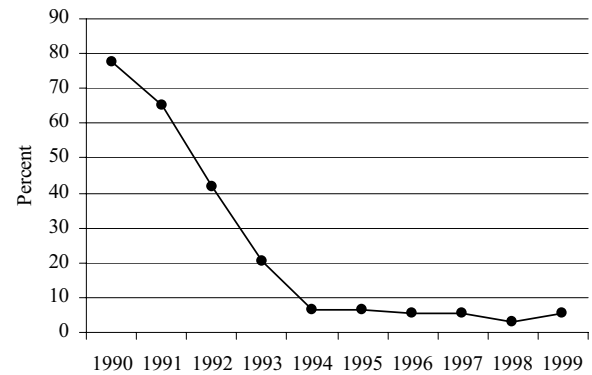
Fig. 2. Percent of tractors produced that are greater than 100 horsepower.

onset of transition and may not be fully exploiting its resource endowments in a new environment (i.e., the relative abundance of labor with respect to machinery). Russian agriculture inherited a capital-intensive technology from the Soviet era. In order to employ more labor-intensive technology, it is probably necessary for much of the inherited machinery to be replaced. Unfortunately, the poor financial performance of Russia's agricultural sector, as well as the poor performance of the Russian credit market in general, has discouraged investment. The inability to invest in new technology may be one of the main distortions in the input markets that keep farms from using the cost-minimizing (relatively more labor-using) input bundle. Rather than using the very large horsepower machines inherited from the Soviet era, operators would be able to improve EE if they could use smaller scale machinery more suitable to the relative abundance of nonskilled labor on Russian farms. This already appears to be happening to some degree. What little machinery that was produced in the late 1990s was primarily smaller scale tractors (Fig. 2).

5. Conclusions

This study has attempted to answer two main questions. The first broad question is, how much could farm performance be improved if all farms in Russia were to adopt the best domestic practice? According to the TE estimates, output levels could have been maintained while reducing overall input use by an average of 29–32% in 1998, depending on the method used. Put another way, since constant returns to scale were found, output could have been expanded by 29–32% from the same amount of inputs. Furthermore, according to the AE estimates, for the same output target, costs could have been reduced about 30%.

The second question that was addressed was, which input markets suffer from the greatest distortions? All inputs were found to contribute to allocative inefficiency, reflecting markets that function poorly. However, the largest source of allocative inefficiency appears to have been the relative over-utilization of fuels. There may be several possible explanations for this finding. One possibility is that fuel may have been used in the

study period as a barter tool to finance other input purchases or to pay laborers in kind. These additional payments would imply that labor is *de facto* more expensive than the ruble wages would suggest, and therefore not actually underused (the corollary being that the amount of fuel and fertilizer use is actually efficient). Another possibility is that Russian agricultural machinery may be less fuel-efficient than western machinery, due to poor maintenance and the lack of a spare parts market.

Another important source of allocative inefficiency appears to be the relative under-utilization of labor. Rigidities in the labor market, explained by such factors as housing considerations and the use of in-kind payments, help to keep real wages low. The machinery-intensive nature of corporate farming may be inappropriate, given the current low cost of labor relative to machinery and fuel. Farms often find they will perform better by implementing the old machinery-intensive Soviet agricultural practices, rather than responding to market incentives, which would require emphasizing labor-using practices. This is likely related to credit constraints and the lack of a land market in the study period that would have allowed farms to replace their labor-saving machinery with smaller scale, more labor-using machinery.

The relatively machinery-intensive nature of agricultural technology in Russia today is understandable, given the agricultural establishment's preferences for large-scale commercial farms (a preference that was shared by the Soviets). However, Russian agriculture may need to go through a period of relative labor-intensity, given the relatively low real wages in Russia. Early in the twentieth century, agriculture in the United States was relatively more labor-intensive than it is today. Given the proper institutional reforms to allow for more factor mobility, private sector farming in Russia could also evolve over time into large-scale, capital-intensive agriculture.

Finally, it should be noted that the data used in this study were available only for corporate farms. The Russian government has only recently started to publish data on private and subsidiary plot farming. This reflects the bias of the Russian government toward large scale, machinery-intensive farming. One oft-quoted statistic of Russian agriculture is that subsidiary plot farming provides more than 50% of the value of all agricultural production in Russia, while using less than 10% of all available arable land. This figure can be misleading, however, since some of the inputs used in the private plots are "diverted" from corporate farms where the owner of the private plot works. Further research may be needed to explore the extent to which private plot farming in Russia is more cost-efficient than corporate farming.

Appendix A: Using regional average price data to measure allocative efficiency

This appendix shows how to interpret the AE scores derived from oblast-level data, in the special case when the Cobb–Douglas production function can be used to characterize the production process.

Following Schmidt and Lovell (1979) and Kumbhakar (1997), suppose there is a constant returns to scale Cobb–Douglas cost function (derived from the estimated production function) with one output and two inputs, labor and capital, with the possibility of technical and allocative inefficiency. Labeling output and the cost of labor and output, respectively, as y, w_L, and w_K, let the efficient cost be denoted as:

$$C(w_L, w_K, y) = \beta_0 (w_L)^{\beta_L} (w_K)^{\beta_K} y, \tag{A.1}$$

and the resulting input demand functions as $L(w_K, w_L, y)$ and $K(w_K, w_L, y)$. The cost function with TE and AE can be specified as:

$$\tilde{C}(w_L^*, w_K^*, y) = w_L^* \cdot L^e(w_L^*, w_K^*, y) + w_K^* \cdot K^e(w_L^*, w_K^*, y), \tag{A.2}$$

where

$w_L^* = w_L$, $w_K^* = w_K + \varepsilon_K$, and ε_K results in the over- or under-utilization of capital;

$L^e(w_L^*, w_K^*, y) = uL(w_L^*, w_K^*, y)$; and

$K^e(w_K^*, w_K^*, y) = uK(w_K^*, w_K^*, y)$, and $u(0 < u < 1)$ measures input saving TE.

The advantage of this specification is that the cost-minimization problem is well-defined. The farm manager minimizes costs, but misinterprets the signal from the market price, for whatever reason.

Consider the first order conditions for an individual farm, i, of J farms in a region:

$$\frac{K^i(w_K^{*i}, w_K^{*i}, y^i)}{L^i(w_K^{*i}, w_K^{*i}, y^i)} = \frac{\beta_K}{\beta_L} \frac{w_L}{w_K} + \frac{\beta_K}{\beta_L} \frac{\varepsilon_K^i}{w_K}. \tag{A.3}$$

All farms in the region face the same market prices, w_L and w_K, but farm i responds as if facing $w_K + \varepsilon_K^i$. The error term ε_K^i describes the misallocation of capital, and can contain a distortion component common to all firms and a farm-level inefficiency component (Schmidt and Lovell, 1979). To find the systemic component of the error, find the average of the ε_K^i for all farms, weighted by input use. The component of the error due to inefficiency can be found by subtracting the systemic error $\bar{\varepsilon}_K$ from ε_K^i. Thus, the systemic and inefficiency components of farm i's error are:

$$\text{Systemic: } \bar{\varepsilon}_K = \frac{\sum_i \varepsilon_K^i K^i(w_K^*, w_K^*, y)}{\sum_i K^i(w_K^*, w_K^*, y)} \tag{A.4}$$

Inefficiency: $\varepsilon_K^i - \bar{\varepsilon}_K$.

Now suppose that instead of a number of farm-level observations, there is one observation constructed from aggregate data for the region. That is, the prices faced by farms were not available at the individual farm level, but total costs and volumes used were reported at the regional level. Taking total costs and

Table A.1
Efficiency scores for 40 highest agricultural producing oblasts, SFA method, ranked by 1993–1998 average economic efficiency scores

Oblast	Technical efficiency						Allocative efficiency						Economic efficiency (EE)						EE 1993–1998 avg.
	1993	1994	1995	1996	1997	1998	1993	1994	1995	1996	1997	1998	1993	1994	1995	1996	1997	1998	
Tyumen'	0.98	0.97	0.97	0.97	0.96	0.96	0.99	0.97	0.94	0.86	0.95	0.93	0.96	0.94	0.91	0.84	0.92	0.89	0.91
Moscow	0.97	0.97	0.96	0.96	0.95	0.95	0.94	0.93	0.89	0.86	0.83	0.83	0.91	0.90	0.86	0.83	0.79	0.79	0.85
Samara	0.97	0.97	0.97	0.96	0.96	0.95	0.88	0.86	0.73	0.76	0.71	0.74	0.85	0.83	0.71	0.73	0.68	0.70	0.75
Krasnodar	0.90	0.89	0.88	0.87	0.86	0.84	0.93	0.93	0.88	0.85	0.82	0.71	0.84	0.83	0.78	0.73	0.70	0.60	0.75
Ryazan'	0.95	0.95	0.94	0.94	0.93	0.92	0.87	0.88	0.75	0.68	0.63	0.69	0.83	0.83	0.70	0.64	0.59	0.64	0.71
Amur	0.87	0.85	0.84	0.82	0.80	0.78	0.90	0.87	0.81	0.70	0.95	0.86	0.78	0.74	0.67	0.57	0.76	0.67	0.70
Bryansk	0.93	0.92	0.91	0.90	0.89	0.88	0.86	0.83	0.75	0.73	0.63	0.68	0.80	0.77	0.68	0.66	0.56	0.60	0.68
Primor'ye	0.94	0.93	0.92	0.91	0.91	0.90	0.87	0.86	0.82	0.74	0.54	0.58	0.82	0.80	0.76	0.67	0.49	0.52	0.68
Bashkortostan	0.89	0.88	0.86	0.85	0.83	0.82	0.91	0.88	0.73	0.70	0.70	0.75	0.81	0.77	0.63	0.59	0.59	0.61	0.67
Novosibirsk	0.96	0.96	0.95	0.95	0.94	0.93	0.78	0.73	0.66	0.67	0.66	0.67	0.75	0.70	0.63	0.64	0.62	0.63	0.66
Belgorod	0.91	0.90	0.89	0.88	0.87	0.86	0.87	0.81	0.69	0.68	0.70	0.66	0.80	0.73	0.62	0.60	0.61	0.57	0.66
Tver'	0.88	0.86	0.85	0.83	0.82	0.80	0.82	0.85	0.76	0.82	0.72	0.70	0.72	0.73	0.65	0.69	0.59	0.56	0.66
Voronezh	0.86	0.85	0.84	0.82	0.80	0.78	0.89	0.85	0.76	0.72	0.73	0.76	0.77	0.72	0.63	0.59	0.59	0.59	0.65
Chuvashia	0.84	0.83	0.81	0.79	0.77	0.75	0.91	0.87	0.81	0.74	0.74	0.77	0.77	0.72	0.66	0.59	0.57	0.58	0.65
Chelyabinsk	0.80	0.78	0.76	0.74	0.71	0.69	0.90	0.88	0.82	0.80	0.88	0.91	0.72	0.68	0.62	0.59	0.63	0.63	0.65
Kursk	0.86	0.84	0.83	0.81	0.79	0.77	0.85	0.81	0.75	0.72	0.71	0.76	0.73	0.68	0.62	0.58	0.56	0.59	0.63
Tambov	0.84	0.82	0.81	0.79	0.77	0.74	0.89	0.85	0.72	0.72	0.75	0.77	0.75	0.70	0.58	0.57	0.57	0.57	0.63
Tatarstan	0.97	0.97	0.97	0.96	0.96	0.95	0.81	0.77	0.71	0.43	0.56	0.61	0.79	0.75	0.68	0.41	0.54	0.58	0.62
Leningrad	0.85	0.83	0.82	0.80	0.78	0.76	0.81	0.80	0.76	0.76	0.74	0.75	0.69	0.67	0.62	0.61	0.58	0.57	0.62
Stavropol'	0.84	0.82	0.80	0.78	0.76	0.74	0.90	0.80	0.72	0.75	0.73	0.80	0.75	0.65	0.57	0.59	0.56	0.59	0.62
Tula	0.84	0.82	0.80	0.79	0.77	0.74	0.91	0.86	0.73	0.72	0.69	0.70	0.76	0.70	0.58	0.57	0.53	0.52	0.61
Orlov	0.84	0.83	0.81	0.79	0.77	0.75	0.92	0.89	0.77	0.66	0.63	0.63	0.77	0.74	0.62	0.53	0.48	0.47	0.60
Mari-El	0.89	0.88	0.86	0.85	0.83	0.82	0.82	0.73	0.67	0.75	0.63	0.56	0.73	0.64	0.58	0.63	0.53	0.46	0.59
Udmurtia	0.80	0.78	0.76	0.73	0.71	0.68	0.86	0.83	0.77	0.74	0.75	0.76	0.69	0.65	0.58	0.54	0.53	0.52	0.59
Sverdlovsk	0.82	0.80	0.78	0.76	0.74	0.72	0.87	0.86	0.77	0.75	0.73	0.54	0.71	0.69	0.60	0.57	0.54	0.39	0.58
Krasnoyarsk	0.84	0.82	0.80	0.78	0.76	0.74	0.88	0.79	0.72	0.65	0.68	0.68	0.73	0.65	0.58	0.50	0.52	0.50	0.58
Lipetsk	0.79	0.77	0.75	0.73	0.70	0.68	0.88	0.89	0.79	0.73	0.68	0.73	0.70	0.69	0.59	0.53	0.48	0.49	0.58
Kemerovo	0.81	0.79	0.77	0.75	0.72	0.70	0.86	0.82	0.65	0.75	0.69	0.70	0.69	0.65	0.50	0.56	0.50	0.49	0.56
Perm'	0.75	0.72	0.70	0.67	0.64	0.61	0.88	0.87	0.77	0.79	0.84	0.77	0.66	0.63	0.54	0.53	0.54	0.47	0.56
Rostov	0.85	0.83	0.82	0.80	0.78	0.76	0.87	0.84	0.70	0.66	0.53	0.46	0.74	0.70	0.58	0.53	0.41	0.35	0.55
Saratov	0.82	0.81	0.79	0.77	0.75	0.72	0.88	0.82	0.68	0.69	0.54	0.53	0.73	0.66	0.54	0.53	0.40	0.38	0.54
Altay Krai	0.74	0.71	0.69	0.66	0.63	0.60	0.90	0.85	0.70	0.72	0.71	0.70	0.66	0.60	0.48	0.47	0.44	0.42	0.51
Omsk	0.76	0.74	0.71	0.69	0.66	0.63	0.84	0.80	0.69	0.63	0.54	0.61	0.64	0.59	0.49	0.43	0.36	0.39	0.48
Penza	0.71	0.68	0.65	0.62	0.59	0.56	0.87	0.80	0.69	0.68	0.72	0.77	0.61	0.55	0.45	0.42	0.42	0.43	0.48
Ul'yanovsk	0.87	0.85	0.84	0.82	0.81	0.79	0.74	0.68	0.52	0.49	0.48	0.51	0.64	0.58	0.44	0.41	0.38	0.40	0.48
Kirov	0.73	0.70	0.67	0.65	0.62	0.58	0.77	0.81	0.71	0.63	0.64	0.65	0.56	0.57	0.48	0.41	0.40	0.38	0.47
Nizhniy Novgorod	0.72	0.69	0.67	0.64	0.60	0.57	0.83	0.80	0.71	0.66	0.62	0.61	0.60	0.56	0.47	0.42	0.37	0.35	0.46
Volgograd	0.62	0.59	0.55	0.52	0.48	0.45	0.95	0.91	0.79	0.76	0.75	0.77	0.59	0.53	0.44	0.39	0.36	0.34	0.44
Irkutsk	0.64	0.61	0.58	0.54	0.51	0.47	0.85	0.82	0.74	0.69	0.72	0.74	0.54	0.50	0.43	0.38	0.37	0.35	0.43
Orenburg	0.64	0.60	0.57	0.54	0.50	0.46	0.87	0.80	0.69	0.66	0.68	0.70	0.55	0.48	0.39	0.35	0.34	0.32	0.41
Kurgan	0.64	0.61	0.58	0.55	0.51	0.48	0.87	0.81	0.71	0.64	0.60	0.62	0.56	0.50	0.41	0.35	0.31	0.30	0.40
Russia avg.	0.83	0.82	0.80	0.78	0.76	0.74	0.87	0.84	0.74	0.71	0.70	0.70	0.73	0.69	0.60	0.56	0.54	0.52	0.60

dividing by total volume for the region is equivalent to weighting by input share, as shown above. The price for capital faced by the representative farm is:

$$w_K + \frac{\sum_i \varepsilon_K^i K^i\left(w_K^*, w_K^*, y\right)}{\sum_i K^i\left(w_K^*, w_K^*, y\right)} = w_K + \bar{\varepsilon}_K. \tag{A.5}$$

The first-order condition becomes:

$$\frac{K^J\left(w_K^*, w_K^*, y\right)}{L^J\left(w_K^*, w_K^*, y\right)} = \frac{\beta_K}{\beta_L}\frac{w_L}{w_K} + \frac{\beta_K}{\beta_L}\frac{\bar{\varepsilon}_K}{w_K}. \tag{A.6}$$

Thus, the regional average price contains information only about the systemic component of allocative inefficiency. It is important to note that this approach assumes that prices faced by farms are the same within a region, but that prices can differ between regions.

Appendix B: Discussion of shadow prices for land

The derived shadow prices for land may be useful for those interested in the debate on land reform in Russia. The shadow land prices were derived from the cost-function dual to the

Table A.2

Efficiency scores for 40 highest agricultural producing oblasts, DEA method, ranked by 1993–1998 average economic efficiency scores

Oblast	Technical efficiency						Allocative efficiency						Economic efficiency (EE)						EE 1993–1998 avg.
	1993	1994	1995	1996	1997	1998	1993	1994	1995	1996	1997	1998	1993	1994	1995	1996	1997	1998	
Tyumen'	0.62	1.00	1.00	1.00	1.00	1.00	0.91	0.80	1.00	0.86	1.00	1.00	0.56	0.80	1.00	0.86	1.00	1.00	0.87
Astrakhan'	1.00	1.00	1.00	1.00	1.00	1.00	0.89	0.65	0.98	0.60	1.00	1.00	0.89	0.65	0.98	0.60	1.00	1.00	0.85
Krasnodar	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.87	0.84	0.74	0.67	1.00	0.98	0.87	0.84	0.74	0.67	0.85
Moscow	1.00	1.00	0.88	1.00	0.83	0.95	0.92	1.00	0.82	1.00	0.84	0.79	0.92	1.00	0.71	1.00	0.70	0.75	0.85
Samara	0.57	1.00	0.88	1.00	1.00	1.00	0.86	0.75	0.73	0.89	1.00	0.87	0.49	0.75	0.64	0.89	1.00	0.87	0.77
Stavropol'	0.93	0.85	0.94	0.90	0.84	1.00	0.84	0.80	0.70	0.82	0.80	0.78	0.78	0.68	0.66	0.74	0.67	0.78	0.72
Belgorod	0.95	0.89	0.77	0.79	0.75	0.90	0.84	0.83	0.70	0.79	0.78	0.80	0.80	0.73	0.53	0.62	0.59	0.72	0.66
Ryazan'	0.62	0.87	0.67	0.85	0.78	0.96	0.81	0.83	0.79	0.81	0.89	0.85	0.50	0.73	0.52	0.69	0.69	0.82	0.66
Novosibirsk	0.85	1.00	1.00	0.99	0.72	0.80	0.74	0.65	0.75	0.61	0.85	0.82	0.63	0.65	0.75	0.60	0.61	0.65	0.65
Tatarstan	1.00	1.00	0.98	1.00	1.00	0.80	0.78	0.86	0.63	0.51	0.63	0.63	0.78	0.86	0.61	0.51	0.63	0.50	0.65
Chuvashia	1.00	0.89	0.88	0.78	0.84	0.86	0.77	0.76	0.67	0.80	0.69	0.70	0.77	0.67	0.59	0.62	0.58	0.60	0.64
Bryansk	0.93	0.85	0.67	0.62	0.66	0.86	0.81	0.91	0.80	0.96	0.65	0.79	0.75	0.77	0.53	0.59	0.43	0.68	0.63
Amur	1.00	0.96	0.52	0.57	0.66	0.83	0.83	0.84	0.82	0.83	0.77	0.85	0.83	0.80	0.43	0.47	0.51	0.70	0.62
Rostov	0.95	1.00	0.99	0.75	0.83	0.90	0.73	0.73	0.71	0.76	0.65	0.51	0.69	0.73	0.70	0.58	0.54	0.45	0.62
Primor'ye	0.83	0.74	0.87	0.74	0.50	1.00	0.82	0.84	0.74	0.77	0.90	0.71	0.68	0.62	0.64	0.58	0.45	0.71	0.61
Kursk	0.86	1.00	0.64	0.67	0.61	0.75	0.79	0.83	0.80	0.88	0.74	0.82	0.68	0.83	0.51	0.59	0.45	0.61	0.61
Voronezh	0.89	0.85	0.67	0.60	0.69	0.80	0.84	0.84	0.80	0.82	0.79	0.79	0.75	0.71	0.53	0.49	0.55	0.63	0.61
Chelyabinsk	0.81	0.88	0.68	0.82	0.91	1.00	0.73	0.78	0.65	0.74	0.92	0.48	0.59	0.68	0.44	0.60	0.84	0.48	0.60
Bashkortostan	0.68	0.70	0.75	0.81	0.85	0.60	0.84	0.88	0.71	0.80	0.79	0.83	0.57	0.62	0.53	0.64	0.67	0.50	0.59
Mari-El	0.81	0.78	0.78	1.00	0.64	0.75	0.77	0.85	0.71	0.73	0.72	0.64	0.63	0.66	0.55	0.73	0.46	0.48	0.59
Tambov	0.87	0.92	0.78	1.00	0.62	0.76	0.79	0.76	0.57	0.57	0.80	0.81	0.69	0.70	0.45	0.57	0.50	0.61	0.59
Komi	1.00	1.00	0.54	0.51	0.59	0.65	0.97	0.77	0.80	0.78	0.67	0.82	0.97	0.77	0.43	0.39	0.39	0.53	0.58
Leningrad	1.00	0.99	0.74	0.72	0.72	0.66	0.74	0.66	0.72	0.72	0.69	0.70	0.74	0.65	0.53	0.52	0.50	0.47	0.57
Kabardino-Balkaria	0.70	0.81	0.71	1.00	0.98	0.56	0.73	0.74	0.58	0.68	0.80	0.74	0.51	0.60	0.41	0.68	0.78	0.42	0.57
Dagestan	1.00	1.00	1.00	1.00	1.00	0.82	0.63	0.67	0.61	0.67	0.50	0.36	0.63	0.67	0.61	0.67	0.50	0.30	0.56
Kaluga	0.81	1.00	0.57	0.60	0.42	0.57	0.84	0.85	0.80	0.87	0.82	0.84	0.68	0.85	0.46	0.52	0.35	0.48	0.56
Krasnoyarsk	1.00	0.82	0.65	0.57	0.59	0.69	0.82	0.71	0.72	0.69	0.86	0.77	0.82	0.58	0.47	0.40	0.50	0.53	0.55
Orlov	0.77	0.88	0.60	0.59	0.53	0.75	0.86	0.85	0.80	0.79	0.77	0.69	0.66	0.74	0.48	0.46	0.41	0.52	0.55
Tula	0.71	0.97	0.72	0.66	0.48	0.57	0.83	0.83	0.72	0.80	0.79	0.81	0.59	0.80	0.52	0.53	0.38	0.46	0.55
Saratov	0.73	1.00	0.99	1.00	0.79	0.40	0.74	0.75	0.50	0.66	0.69	0.66	0.54	0.75	0.49	0.66	0.55	0.26	0.54
Lipetsk	0.90	0.85	0.53	0.58	0.52	0.66	0.83	0.86	0.78	0.76	0.73	0.76	0.75	0.73	0.41	0.44	0.38	0.51	0.54
North Osetia	0.57	0.68	0.94	0.93	0.74	1.00	0.66	0.77	0.61	0.64	0.63	0.64	0.37	0.52	0.57	0.59	0.47	0.64	0.53
Tver'	0.67	0.98	0.59	0.62	0.42	0.60	0.74	0.89	0.78	0.84	0.82	0.79	0.50	0.87	0.46	0.52	0.34	0.47	0.53
Khabarovsk	1.00	0.88	0.72	0.64	0.61	1.00	0.76	0.63	0.66	0.64	0.56	0.61	0.76	0.56	0.48	0.41	0.34	0.61	0.53
Yaroslavl'	0.70	1.00	0.71	0.64	0.55	0.47	0.81	0.86	0.73	0.74	0.71	0.72	0.57	0.86	0.52	0.47	0.39	0.34	0.52
Altay Krai	1.00	0.71	0.76	0.64	0.39	0.62	0.87	0.68	0.63	0.75	0.78	0.80	0.87	0.48	0.48	0.48	0.30	0.49	0.52
Adygea	0.68	0.66	0.60	0.68	0.57	0.83	0.84	0.89	0.78	0.73	0.69	0.71	0.57	0.59	0.47	0.49	0.39	0.58	0.52
Udmurtia	0.78	0.87	0.55	0.49	0.48	0.54	0.80	0.88	0.83	0.86	0.83	0.79	0.62	0.76	0.46	0.42	0.40	0.43	0.51
Tomsk	0.83	0.83	0.65	0.47	0.61	0.78	0.78	0.73	0.73	0.76	0.70	0.67	0.65	0.61	0.48	0.35	0.42	0.53	0.51
Ivanovo	0.67	0.77	0.57	0.68	0.42	0.40	0.84	0.94	0.85	0.80	0.87	0.85	0.56	0.72	0.48	0.54	0.36	0.34	0.50
Russia avg.	0.77	0.83	0.65	0.66	0.61	0.68	0.78	0.77	0.71	0.73	0.75	0.70	0.60	0.64	0.46	0.48	0.45	0.48	0.65

estimated Cobb–Douglas production function, where land is treated as quasi-fixed.

Assuming that land is quasi-fixed means leaving the price of land out of the cost-minimization problem, so with a Cobb–Douglas production function with land (x_A), labor (x_L), and capital (x_K), the optimization problem looks like so:

$$\min_{w_K, w_L} w_K \cdot x_K + w_L \cdot x_L + w_A^s \cdot x_A \quad \text{s.t.} \ Y = A x_K^\alpha x_L^\beta x_A^\delta,$$

(B.1)

where w_K is the rental price of capital, w_L the wage, and w_A^s the price of land (with the *s* reminding us that this is a shadow price,

since no land price in Russia can be observed). The resulting cost function is:

$$C(Y, w_K, w_L, x_A) = K \cdot \left(\frac{Y}{A x_A^\delta} \right) \cdot w_K^{\frac{\alpha}{\alpha+\beta}} \cdot w_L^{\frac{\beta}{\alpha+\beta}} + w_A^s \cdot x_A,$$

(B.2)

where

$$K(\alpha\beta) = \alpha^{\frac{\alpha}{\alpha+\beta}} \cdot \beta^{\frac{-\beta}{\alpha+\beta}} + \beta^{\frac{\beta}{\alpha+\beta}} \cdot \alpha^{\frac{-\alpha}{\alpha+\beta}}.$$

In the long run, the amount of x_A will be adjusted so that the cost function is at a local optimum, so that the first derivative of the above cost function with respect to x_A will be equal to zero:

Table B.1
Shadow land prices per hectare (annual rental price), adjusted for land quality, in dollars

District/Year	1993	1994	1995	1996	1997	1998	Quality weights
Russia	11.25	13.75	14.93	16.28	16.43	10.49	1.00
Northern District	28.27	37.12	42.27	45.21	39.85	27.43	0.75
Northwest District	23.71	31.19	35.68	33.29	37.03	24.41	0.84
Central District	12.49	17.57	18.52	18.81	17.91	11.99	1.11
Volga-Vyatka District	11.59	15.91	16.61	18.73	18.62	11.77	0.96
Central Black Earth District	9.78	11.51	13.52	13.09	13.04	8.97	1.49
Povolzhsky District	12.30	14.44	14.72	15.69	16.50	10.03	0.94
North Caucasian District	8.72	8.96	9.95	12.81	13.33	8.39	2.08
Urals District	12.19	15.69	15.90	18.91	19.04	11.75	0.79
Western-Siberian District	10.31	12.21	14.30	16.64	16.63	10.92	0.83
Eastern-Siberian District	11.72	14.74	17.96	15.73	15.10	9.84	0.91
Far East District	25.00	37.20	38.43	29.54	33.73	17.48	0.80

$$\frac{\partial C(Y, w_K, w_L, x_A)}{\partial x_A} = w_A^s - \frac{\delta x_K}{\alpha + \beta} \cdot \left(\frac{Y}{A}\right)^{\frac{1}{\alpha+\beta}}$$
$$\cdot w_K^{\frac{\alpha}{\alpha+\beta}} \cdot w_L^{\frac{\beta}{\alpha+\beta}} \cdot x_K^{(\frac{-\delta}{\alpha+\beta})^{-1}}$$
$$= 0. \qquad (B.3)$$

Assuming that actual land use is consistent with w_A^s, the long-run opportunity cost of land, w_A^s can be calculated using (B.3) Appendix Table B.1 lists the shadow prices by oblast in the Russian Federation in dollars. Note that these are prices of quality-adjusted land.[13] The different prices in Table B.1 therefore represent the relative scarcity of land, rather than its quality. Prices for land that include a premium for quality can be obtained by multiplying the price in question by the corresponding quality adjustment.

Land prices were found to range from US$5 to US$230 per hectare, while the average for the Russian Federation was US$14. Land prices in Krasnodar and Rostov, the two most productive regions in Russia, were US$10.50 and US$8.

The oblasts with the highest AE scores had relatively high shadow prices of land. High (quality adjusted) land shadow prices are also generally associated with low land/labor and land/tractor ratios. In Yakutia, where the land prices were the highest, the ratio of land to labor was 0.021 (the lowest in the sample). The average for the Russian Federation is 0.134.

Table B.2 compares the price and land/labor ratio in the Russian Federation to those in North Dakota. North Dakota produces wheat and barley, the main crops produced in Russia. One striking statistic is the average amount of land a Russian

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[13] An oblast with traditionally high yields has its total land use increased according to the extent that its yield exceeds the average for the Russian Federation.

Table B.2
Comparison of land prices and incomes in Russia and United States, 1996

	Land price $/acre	Acres per laborer ratio	Annual farmer income dollars	Income/land price ratio
North Dakota				
Wheat production	43	1,290	54,128	1,258.8
Barley production	32	1,290	26,032	813.5
Russian Federation	16	46	326	20.4

Source: U.S. Department of Agriculture, 1999; Russian Ministry of Agriculture.

farmer works, about 46 acres per worker, compared to 1,290 for farmers in North Dakota. The cost of using an acre of farmland for a year in 1996 was US$16 in Russia, which is less than the cost of a hectare in North Dakota, US$43 for wheat and US$32 for barley.

While it seems that there are far too many laborers on farms in Russia, the table shows the relative price of land to laborers in the Russian Federation. Labor is significantly less expensive compared with land in the Russian Federation (reflecting labor market rigidities discussed earlier), justifying a higher ratio of labor to land in agricultural production. The relatively inexpensive labor in Russia also partly explains why the most efficient agricultural enterprises in Russia are those whose cost shares of labor are the highest.

The relatively low land prices in Russia are likely a result of the poor EE of agricultural production. Since the creation of a land market would provide incentives to increase agriculture's EE, the prices for land would probably rise in the long run as a result of land reform.

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